PERFORMANCE OF REFRIGERATOR OPERATING WITH AND WITHOUT LIQUID-SUCTION HEATING

LOH WING LIONG

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Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

A modern refrigeration system consists of four main components which is a compressor, a condenser, an evaporator and a throttling device. There are many researches which have been conducted in order to achieve good performance of the refrigeration system such as two stage refrigeration system, energy systems and suction heating. Suction heating is based on the concept of heat transfer between the capillary tube and suction tube. Suction heating is applied in order to absorb heat and thus lowering the temperature if the refrigerant at the capillary tube. The main purpose of this project is to investigate the performance of refrigeration operating with and without liquid suction heating in order to investigate how much the suction heating influence the performance of the refrigeration system. The project is based on experimental study on refrigeration system test rig and two setup of experimental studies which is the experimental setup for refrigeration operating with suction heating and experimental setup for refrigeration operating without suction heating. Both sets of system configuration will be run until it reaches steady operating condition before data is collected in order to calculate the coefficient of performance (COP). Results show that the refrigeration system operating with liquid suction heating has the highest value of COP which is 2.14 compare with the system operating without suction heating which is 1.8. The percentage difference in COP is about 15.89 percent.

ABSTRAK

Sistem penyejukan moden terdiri daripada empat komponen utama iaitu pemampat, pemeluwap, penyejat dan tiub kapilari. Terdapat banyak penyelidikan yang telah dijalankan untuk mencapai prestasi baik sistem penyejukan seperti dua peringkat sistem penyejukan, sistem tenaga dan pemanasan sedutan. Pemanasan sedutan adalah berdasarkan konsep pemindahan haba antara tiub kapilari dan tiub sedutan. Pemanasan sedutan digunakan untuk menyerap haba dan seterusnya mengurangkan suhu jika penyejuk di tiub rerambu Tujuan utama projek ini dijalankan adalah untuk mengenal pasti prestasi antara sistem peti sejuk yang beroperasi dengan kaedah pemindahan haba dan sistem yang tidak beroperasi dengan pemindahan haba untuk menyiasat berapa banyak pemanasan sedutan mempengaruhi prestasi sistem penyejukan. Projek ini adalah berdasarkan kajian eksperimen pelantar ujian sistem penyejukan dan dua persediaan kajian eksperimen yang setup eksperimen bagi operasi penyejukan dengan pemanasan sedutan dan persediaan eksperimen bagi penyejukan beroperasi tanpa pemanasan sedutan. Kedua-dua set konfigurasi sistem akan berjalan sehingga ia mencapai keadaan operasi yang tetap sebelum data dikumpul untuk mengira pekali prestasi (COP). Hasil kajian menunjukkan bahawa sistem penyejukan yang beroperasi dengan pemanasan sedutan cecair mempunyai nilai tertinggi COP yang adalah 2.14 berbanding dengan sistem operasi tanpa pemanasan sedutan yang ialah 1.8. Perbezaan peratusan dalam COP adalah kira-kira 15.89 peratus.

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LIST OF ABBREVIATIONS

COP	Coefficient of Performance
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineer

LIST OF SYMBOLS

Q_L	Cooling load
Q_H	Heat rejected
W_{in}	Compressor work
T-s	Temperature – entropy
p-h	Pressure - enthalpy

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The refrigeration system cycle is based on the working principle of the vapor-compression refrigeration cycle which is modified from the reversed Carnot cycle. The continuous improvement and modifications of the reversed Carnot cycle have resulted in the introduction of the vapor-compression refrigeration cycle and until now, the household refrigeration and air conditioning working principle is based on this cycle. From the time Jacob Perkins an Englishman, built a prototype of closed cycle ice machine based on the vapor compression cycle in 1834 and were commercialized by Alex Twinning in 1850, continuous research and experiments have been done to enhance the performance of the refrigerator based on higher efficiency and cost saving.

A basic refrigeration system consists of four important component and devices which is the compressor, condenser, evaporator and an expansion valve. Based on the vapor compression refrigeration cycle, these four components and devices will influence the efficiency of the refrigeration system which is measured by its coefficient of performance (COP). The effectiveness of each components and devices working functionality will directly influence the performance of the whole refrigeration system. The influence of these four components have on the performance of the whole refrigeration system is very conclusive that most research and studies to improve the performance of the refrigeration system is mostly based on these four components.

The rate and amount at which the condenser discharges the heat to the environment and also the rate and amount which the evaporator absorbs heat from the compartment can be a measure of performance and efficiency of the refrigeration system. However, the expansion device is also an important device that is currently under extensive research and studies as to increase the performance of the refrigeration system based on reheating process. The expansion device can be either a expansion valve or capillary tube which is used to expand the refrigerant to low temperature and pressure before entering evaporator. From the model of the research done by Klein (2000) using liquid-suction heat exchanger, high temperature refrigerant from the condenser was sub cooled prior to entering the throttling device using the low temperature refrigerant from the evaporator as the heat sink.

Basic model of capillary tube-liquid suction tube heat exchanger is built to model the function of heat exchanger due to its simplicity and also it's significant in the performance study of the refrigeration system. In this model, the liquid suction tube will be wounded outside along the capillary tube which is connecting the condenser and evaporator. By doing so, the heat exchange between the capillary tube and liquid suction tube will be more direct and thus reducing the heat loss effect to the surrounding air. The different of length of liquid suction tube wounded along the capillary tube will influence the heat exchange and thus a optimum length will be determined. The performance studies of the refrigeration will also be done to compare between the coefficient of performance (COP) of the refrigeration system with and without liquid suction heating.

Several unaffected parameters which will not influenced the performance studies of the refrigeration will be considered constant such as the refrigerant mass flow rate, heat loss to surrounding, type of refrigerant (R-134a) and also the heat transfer in the evaporator and condenser is constant. Nevertheless, these parameters will indirectly affect the coefficient of performance of the refrigeration system, however, since the effect is minimal and will not influence with the studies, they are conceded constant.

In this project, the refrigeration system will be operated with and without liquid suction heating. Literature on the fundamental calculations and important points of interest in determination of the performance of the refrigeration system is done in order to obtain the frame of reference besides the studies from other researchers. The contents will prove the contribution of suction heating to refrigeration performance and also the affordability to remove suction heating by using secondary source heat for heating the refrigerant before undergoing compression work. The parameter used to measure the performance of the refrigeration system is coefficient of performance (COP).

1.2 PROBLEM STATEMENT

The performance study of refrigeration system is a topic of interest whereby lots of studies and research have been done in order to improve the performance of the refrigeration system by reducing the workload particularly the compressor work and capillary tube. Thus, by identifying and modifying the parameters of interest which is the liquid suction heat exchanger operating at the throttling device that connects between condenser and evaporator together, a study of performance of refrigeration operating with and without liquid suction heating could be done using the coefficient of performance (COP) as a measured of performance for the suction heating. Nevertheless, suction heating would require additional time and cost to either brazing the suction tube with the capillary tube or winding up the suction tube around the capillary tube. Since the main purpose of suction heating is to increase the refrigerant temperature at the compressor suction line, it have been suggested that utilizing the motor heat from the hermetic metal casing of the compressor is sufficient enough to ensure the refrigerant is fully vaporize before entering the compressor thus reducing the work load of the compressor.

1.3 OBJECTIVES

The main objective on this project is to investigate and analyze performance of the refrigerator operating with and without the liquid suction heating.

1.4 SCOPES

i. Literature and fundamental study on refrigeration system and effect of suction heating

The literature research and review mainly focused on understanding of basic refrigeration cycle and the components of the refrigeration system. Besides, the literature is also widened to include to on the study of suction heating and its effect on the performance study of the refrigeration system. The important parameter needed as a measure of efficiency and performance of refrigeration system such as the refrigerant load, compressor work and the coefficient of performance.

ii. Fabrication of experimental rig for with suction heating

The fabrication of suction heating is done by coiling the suction tube around the capillary tube to allowed heat exchange to occur between the capillary tube and the suction tube of the compressor. The setting up of the experiment is done by isolating between the suction tube and capillary tube to produce experiment without suction heating and then brazing or coiling of suction tube with capillary tube to conduct experiment with suction heating.

iii. Conducting experiment of refrigeration system with and without suction heating

The experiment of the project on the refrigeration system will be conducted based on two parameters, which is with suction heating and without suction heating. The measure of performance for the parameter is based on the calculation of COP. The higher the COP, the better the performance of the refrigeration system.

iv. Analysis of the data collected

Based on the collected data for both experiment with and without suction heating, a detailed calculation is done and the important parameters needed to get the coefficient of performance (COP) is calculated. From the analysis, the COP value and graph will be obtained and analyze.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In a literature review, the basic operation functions of refrigeration system will be discussed in detail so that a clear overview of refrigeration system is obtained. Besides, the suction heating in refrigeration system will also be analyzed and discussed in this chapter in order to understand the function of suction heating and its contribution to the performance and efficiency of the refrigeration system. The cycle encompassed by this refrigeration system which is the ideal vapor compression refrigeration system will also be fully utilized and discussed in this chapter. The ideal vapor compression refrigeration system is very important in this study as it shows the important points to measure the temperature and pressure of the refrigeration system. The literature review will also include the study of the devices involved in operating the refrigeration system. The basic functions of each device will be discussed and the contributions and importance of each device in the system will be briefly explained. Nevertheless, the frame of reference for the measurement of the performance of the refrigeration system will be established for the study done by researcher and also doing preliminary experimental study of the operating refrigeration system. The important parameter involves in determining the performance of refrigeration system will be included in this literature review and so is the theoretical and the formula needed for calculation.

2.2 THERMODYNAMICS LAW AND REFRIGERATION SYSTEM

In order to understand the basic function of refrigeration system, there are two important thermodynamics law that needs to be understood. The first law is the First Law of Thermodynamics. The First Law of Thermodynamics states that energy is a thermodynamics property. The First Law also states that energy cannot be created nor destroyed but rather change from one form to another form of energy (Cengel, 2007). Mainly, the statement from the First Law of Thermodynamics intends to focus on the conservation of energy. However, a process which satisfies the First law of Thermodynamics does not necessarily mean the process will take place unless it satisfies the Second Law of Thermodynamics. The Second Law of Thermodynamics states that energy actually has quality as well as quantity and the processes occur in the direction of decreasing quality energy (Cengel, 2007). This goes to show that heat, a type of energy, and flows from a hotter environment to the colder environment.

Nevertheless, German physicist and mathematician, Rudolf Julius Emanuel Clausius, with his statements "It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower temperature body to a higher temperature body" (Cengel, 2007), have shed light on the operation of refrigeration systems without violating the Second Law of Thermodynamics. The statement generally implies that, for cyclic devices such as refrigerator to transfer heat from colder to hotter space, an external power source is needed to be consumed whereby it could be said that the compressor is driven by an external power source (Cengel, 2007). The amount of power consumed to operate the compressor will be considered to calculate the performance and efficiency of the refrigeration system in the latter stage.

2.3 VAPOR COMPRESSION REFRIGERATION CYCLE

2.3.1 Carnot Refrigeration Cycle

The Carnot cycle is a totally reversible cycle which consists of two reversible isothermal and two isentropic processes. Carnot cycle serves as the standard against any actual power cycles due to its maximum thermal efficiency. All the four processes are reversible and by reversing the cycles, the directions of the heat and work interactions also been reversed. The resulting reversed Carnot cycle is also called the Carnot refrigerator or the Carnot heat pump as shown in Figure 2.1(a). The process flow that occurs if the reversed Carnot cycle is executed within the saturation dome of a refrigerant as shown from Figure 2.1(b) can be considered as the most efficient refrigeration cycle operating between two specified temperature levels. In process 1-2 the refrigerant will absorbs heat isothermally from a low temperature source at T_L in the amount of Q_L. The refrigerant is then isentropically compressed to state 3 where the temperature will rises to T_H from process 2-3. From process 3-4, the heat at temperature, T_H, is then rejected isothermally to high temperature sink in the amount of Q_H. During the course of the process 3-4 also, the refrigerant changes from saturated vapor state to saturated liquid state which occur in the condenser. After rejecting the heat isothermally, the refrigerant is then expanded isentropically to state 1 and the temperature of the refrigerant also drops to T_L.

$$\text{The heat absorbed, } Q_L = h_2 - h_1 \quad \frac{kJ}{kg} \tag{2.1}$$

$$\text{The heat rejected, } Q_H = h_3 - h_4 \quad \frac{kJ}{kg} \tag{2.2}$$

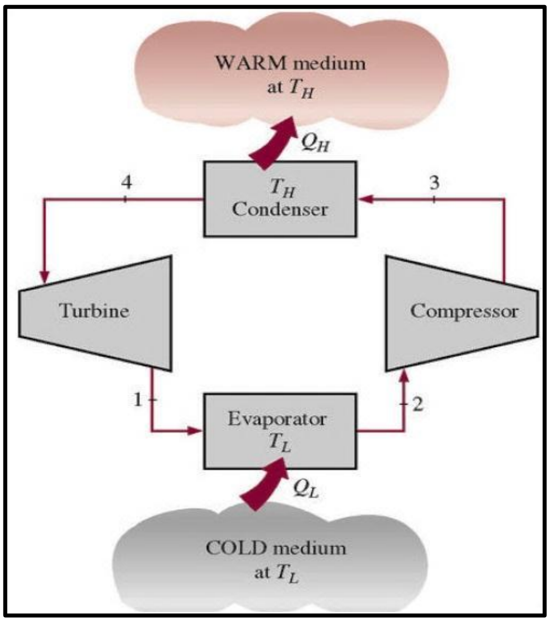
$$\text{The compressor work, } W_{in} = h_3 - h_2 \quad \frac{kJ}{kg} \tag{2.3}$$

The COP for refrigerator is also expressed as

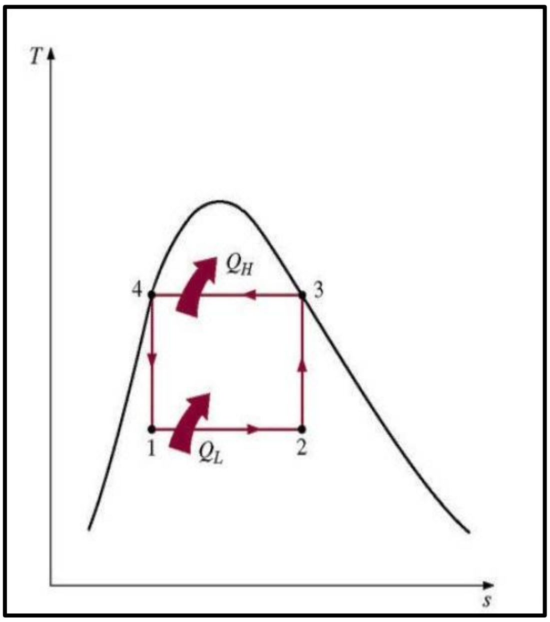
$$COP = \frac{Q_L}{W_{in}} \tag{2.4}$$

As the difference between both the temperatures decreases, the COP also increases which is either T_H falls or T_L rises.

These cycles however cannot be a suitable model in practice using the refrigerator devices. The process from 2 to 3 and also 4 to 1 could not be achieved as it will require the compressor to handle two phases of mixture at one which is unachievable and also the turbine to expand the high moisture content refrigerant in a turbine. It is highly impossible for compressor to handle two phases of the refrigerant at the same time and also expansion of high moisture content in turbine will cause the turbine to cavitate as results of corrosion. Therefore, the reversed Carnot cycle could only be used as a standard against which actual refrigeration cycles are compared (Cengel, 2007).



(a)



(b)

Figure 2.1: Reversed Carnot Cycle (a) Carnot heat pump diagram (b) *T*-*s* diagram

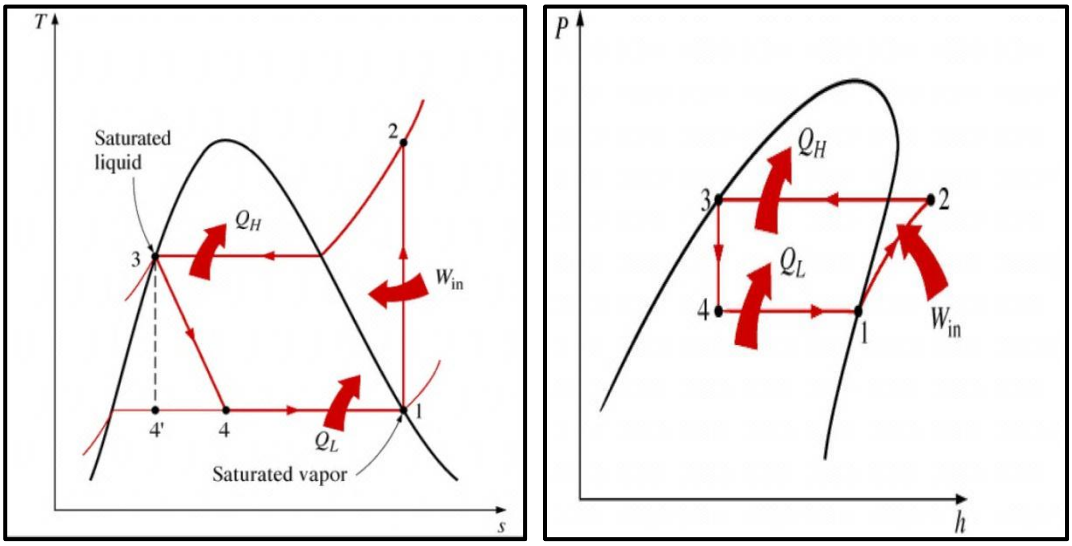
Source: Cengel (2007)

2.3.2 Ideal Vapor Compression Refrigeration Cycle

The ideal vapor compression refrigeration cycle is the modifications from the reversed Carnot cycle and is the most suitable and ideal representation of the refrigeration cycles. In ideal refrigeration cycle, the process refrigerant before entering compressor was vaporized completely and the expansion valve was used to replace the turbine to create a low quality mixture of refrigerant. Although it does not clearly depict the actual vapor compression refrigeration cycle, however it is the most idealistic representation of the refrigeration cycle. In this cycle, the devices use is the condenser, evaporator, expansion valve and compressor. In this cycle, the refrigerant will be vaporized completely in the evaporator before entering the compressor to ensure that the compressor is only handling one phase of refrigerant which is saturated vapor. While to expand the refrigerant at the state of saturated liquid, an expansion valve is used to replace the turbine and producing a low quality mixture of liquid and vapor at a very low temperature and pressure before entering the evaporator.

Figure 2.2 is the ideal vapor compression refrigeration cycle diagram whereby, Figure 2.2(a) is the temperature-entropy (*T*-*s*) diagram of the cycle and Figure 2.2(b) is the pressure-enthalpy (*p*-*h*) diagram of the cycle. Both of the diagrams show the ideal flow process of the refrigerant inside the refrigeration system. There are a total of four stages of operation that the refrigerant has to go through inside the refrigeration system and each stage is accomplished by a device that will process the refrigerant entering the devices. Thus, the refrigeration system is made up of four main devices which are the compressor, evaporator, condenser and throttling device (Ananthanarayanan, 2005).

The ideal vapor compression refrigeration cycle is the simplest most basic cycle used by most refrigeration systems and also air conditioning system to represent the process flow of the cycle. Since its introduction to the world by Jacob Perkins, effort has been made to idealize the vapor compression refrigeration cycle in order to obtain the highest efficiency and performance can be produced by the system. From the name itself, vapor compression refrigeration system, it can be explained that the vapor refrigerant will be compressed to superheated state and being recovered to liquid state by releasing the heat to the heat sink through condenser (Ananthanarayanan, 2005). These vapor recovery processes have saved the industry a huge amount of cost in the need to replenish the refrigerant fervently.



(a) (b)

Figure 2.2: Ideal vapor compression refrigeration cycle (a) *T*-*s* diagram, (b) *p*-*h* diagram

Source: Cengel (2007)

The vapor compression process is started off when the refrigerant enters the compressor at gaseous state at a low temperature. Referring to the reverse Carnot cycle, in order to produce maximum efficiency, the process 1-2 which is the refrigerant compression process, the refrigerant will enter the compressor as a mixture of liquid and gas phase. However, the incompatibility of compressor to handle two phase mixture refrigerant and the cost required for installation it will be difficult to achieve the maximum efficiency. In ideal vapor compression cycle, the refrigerant needs to enter the compressor as saturated vapor gaseous states and thus in reality, the refrigerant will sometimes be superheated before entering the compressor to avoid compressor breakdown.

From the ideal vapor compression refrigeration cycle, the process 1-2 represents the isentropic compression of the refrigerant in the compressor. The refrigerant will enter the compressor as saturated vapor at stage 1 and is isentropically compressed to condenser pressure. After compression, the temperature of the refrigerant is increased to well above the temperature of the surrounding medium which is in the superheated state. The compressor will consume an amount of external power source in order to compress the saturated vapor refrigerant and the amount of work required to isentropically compress the refrigerant is depending on the temperature and pressure of the gaseous refrigerant. This amount of work required by the compressor is consistent with Clacius statement which proves that the Second law of Thermodynamics is not violated (Cengel, 2007).

The refrigerant will then enter the condenser as superheated vapor at state 2. The process 2-3 is the depiction of the constant-pressure heat rejection process in the condenser where the superheated refrigerant will release the heat to the environment from the airflow of surroundings. Like liquid needed latent heat of vaporization to release its molecules from the molecular bond that bind it together to transform into gaseous state, gaseous also needs to release an amount of latent heat of vaporization to transform into liquid state. Thus, due to the change of phase between liquid and gas, an amount of heat which is called the latent heat of vaporization for this stage, is released to the heat sink in order to bond back the molecules to form a molecular bond. The temperature of the refrigerant after releasing heat to the surroundings is still above the temperature of the surroundings and thus needs to undergo another process to dramatically reduce its pressure and temperature.

After undergoing constant-pressure heat rejection process to the surrounding, the temperature of the refrigerant is however still above the temperature of the surroundings. In order to reduce the temperature of the refrigerant dramatically that enables it to absorb heat from the refrigerated space, the refrigerant will need to go through process 4-1. In this process, the refrigerant will flow through a throttling device and expand in order to reduce the temperature and pressure of the refrigerant. In the throttling device, the refrigerant temperature will drop below the temperature of the refrigerated space in order to absorb the heat from the refrigerated space. The process from 4-1 is throttling from the expansion device and the enthalpy of the refrigerant will not change at the end of the process. The saturated liquid refrigerant however turns to low quality saturated mixture refrigerant of liquid and gas at the end of throttling process.

Lastly, the low quality saturated mixture refrigerant will enter the evaporator at a very low pressure and temperature. The process 4-1 is the constant-pressure heat absorption process in the evaporator. The refrigerant mixture will enter the evaporator and completely evaporates by absorbing the heat from the refrigerated space. The refrigerant will then leave the evaporator as saturated vapor and reenters the compressor to complete the cycle. The cycle will continue and the refrigerated space will continue to be cooled by the refrigerant which undergoes the process continuously.

The schematic diagram of the refrigeration system as shown on Figure 2.3 is to give an exemplary view of the devices and the process flow of the refrigeration system. Notice that four main components made up of the refrigeration system is the first the compressor, to compress the refrigerant to higher temperature and pressure. Then the condenser, used to dissipate heat to the environment. The third component is the expansion device to throttle the refrigerant to lower temperature that of the refrigerated space and lastly the evaporator to absorb heat from the refrigerated space.

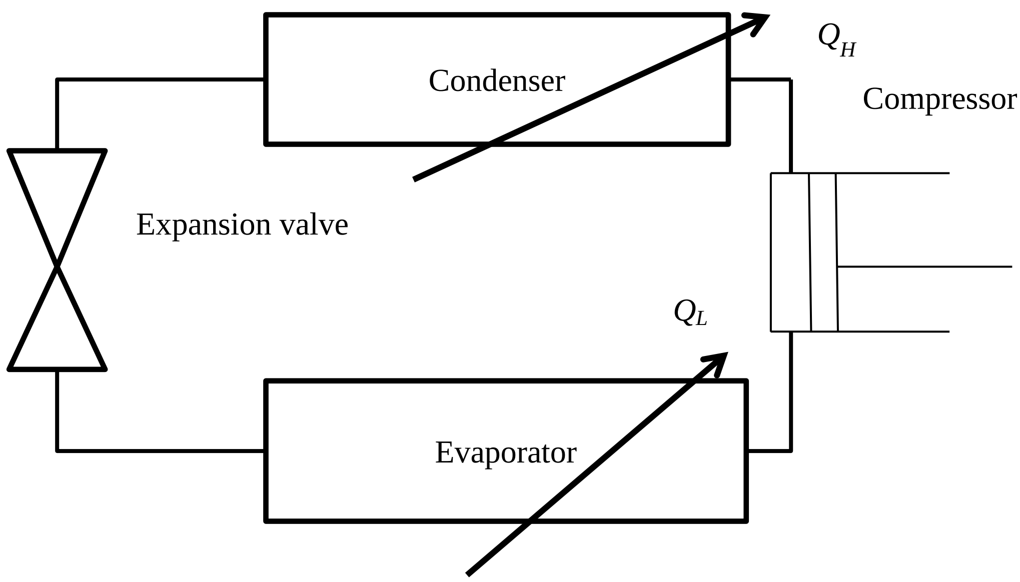


Figure 2.3: Schematic diagram of the vapor compression refrigeration cycle

From Figure 2.2 and Figure 2.3 the regression analysis for the refrigeration capacity, compressor work and coefficient of performance of performance are exactly follows the equation (2.1) to equation (2.4). The equation states that:

The cooling load, Q_L,

$$Q_L = h_1 - h_4 \quad \frac{kJ}{kg}$$

The compressor work input required,

$$W_{in} = h_2 - h_1 \quad \frac{kJ}{kg}$$

Thus, the coefficient of the performance of the refrigerant (COP),

$$COP = \frac{Q_L}{W_{in}}$$

2.3.3 Actual Vapor Compression Refrigeration Cycle

The actual vapor compression cycle is the actual representation of refrigerant behaviour during the cycle flows. In this cycle, several irreversibility was taken into consideration such as fluid frictions and also heat transfer to or from the surroundings. When the refrigerant about to enters the compressor, it is slightly superheated to enable it to completely vaporized. During the transfer of refrigerant from evaporator to compressor, the friction effect will also cause pressure drop and also heat transfer to surroundings to gain (Ananthanarayanan, 2005). Thus, superheating the refrigerant before entering the compressor will compensate for the pressure drop and heat loss. The effect of friction force during the transfer of refrigerant from compressor to condenser will cause the increase and decrease of entropy an also heat transfer. Thus, cooling the refrigerant to the state 2’ is desirable. After flowing from condenser, the refrigerant are not precisely in the state of saturated liquid as it is hard to control the behavior of the refrigerant. Thus, the refrigerant will be sub cooled to ensure it is completely condensed before entering throttling valve.